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OBSERVATIONS ON THE DAUBRÉE EXPERIMENT AND
CAPILLARITY IN RELATION TO CERTAIN
GEOLOGICAL SPECULATIONS

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Those who believe that meteoric waters are an important factor in the production of the phenomena of vulcanism have always met with difficulty in devising a means by which surface waters could reach deep-seated and highly heated regions. This difficulty they have, as they believed, obviated by instancing an experiment made by Daubrée on the passage of water through a porous sandstone against a certain excess counter pressure. That this experiment has no bearing on the question at issue has already been pointed out more than once; but this has apparently not attracted the attention of those who wish to believe in its applicability as a proof of the possibility of introducing accessions of meteoric water into the magma. Accordingly we propose to discuss this experiment and the laws governing capillary processes (of which it is an example); and we endeavor to point out the limitations which must be borne in mind when capillary effects are adduced as important factors in the production of geological phenomena such as vulcanism.

Daubrée's experiment.—In this experiment, which was performed in 1861, Daubrée found that water would pass through a disk of

sandstone, 2 cm. in thickness, in spite of a certain excess counter pressure of steam; his apparatus is represented¹ schematically in Fig. 1. A disk of Strasburg sandstone was clamped between two chambers, the upper one (*L*), open at the top, containing water, the lower one (*V*), gas-tight and connected to a stop-cock (*C*) and manometer (*M*). The whole rested on carbon blocks, and was

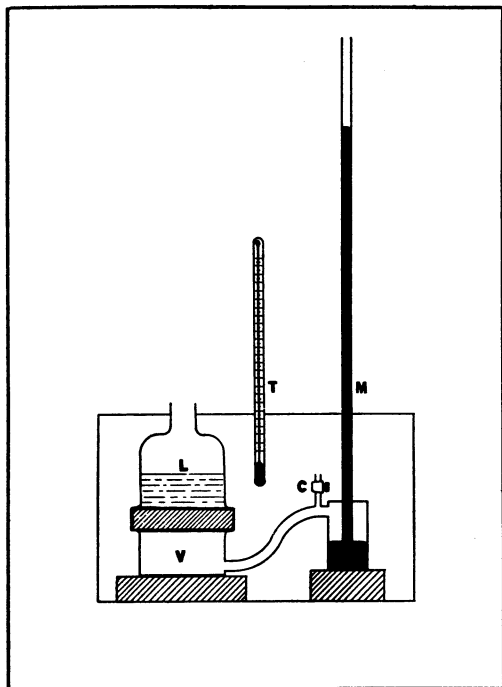


FIG. 1.—Diagram to illustrate the form of apparatus used by Daubrée

placed inside a loosely-closed metal box heated from beneath. Daubrée caused the temperature in the inside of the box (as measured by the thermometer *T*) to remain for some time at 160°, the cock *C* being open meanwhile. Upon closing *C* he observed that the mercury column rose gradually to a height of 68 cm. (0.9 atm.). On relieving the pressure by opening *C*, and subsequently closing it again, he observed the same effect again.

¹ See Daubrée, *Géologie expérimentale*, Paris, 1879, p. 238.

The water was therefore passing through the sandstone against pressure.¹ Daubrée attributed this phenomenon, and rightly, to capillary action, but apparently he was without a clear conception of the physical principles involved; consequently his interpretation of the experiment is in part erroneous and some of his conclusions indefensible. Thus he writes:²

Supposons une cavité séparée des eaux de la surface, marines ou continentales, par des roches qui ne soient pas tout à fait imperméables; admettons, en outre, que cette cavité soit à une profondeur assez grande pour que sa température soit très-élevée: les conditions principales de notre expérience ne se trouveraient-elles pas reproduites? De la vapeur s'accumulerait donc dans cette cavité, et sa tension pourrait devenir bien supérieure à la pression hydrostatique d'une colonne liquide qui remonterait jusqu'à la surface des mers ou des eaux d'alimentation. Et, si l'on est parvenu à mettre en quelque sorte en balance, par l'interposition d'une épaisseur de roche de 2 centimètres seulement, les pressions de deux colonnes, l'une de 2 centimètres d'eau à peine, l'autre de 60 centimètres de mercure, c'est-à-dire de plus de 500 fois supérieure à la première, on ne trouvera plus guère de difficulté à admettre que l'eau descendante devienne la cause du refoulement de laves trois fois plus denses qu'elle, et de leur ascension jusqu'à un niveau bien supérieur au sien. D'après les résultats de l'expérience, l'eau pourrait donc être forcée par la capillarité, agissant concurremment avec la pesanteur, à pénétrer, malgré des contre-pressions intérieures très fortes, des régions superficielles et froides du globe jusqu' aux régions profondes et chaudes, où, à raison de la température et de la pression qu'elle aurait acquises, elle deviendrait capable de produire de grands effets mécaniques et chimiques.

The "atmometer."—The effect observed is, as Daubrée himself recognized, due to capillarity; similar results may be obtained much more simply and directly by means of the so-called "atmometer."³ This consists of a somewhat narrow glass tube,⁴ open

¹ And against a temperature gradient too, since the upper surface of the sandstone was at 100°, the lower surface at some higher temperature; but the effect of this is, as we shall show, altogether subsidiary, except for extreme temperature differences.

² Daubrée, *op. cit.*, pp. 242-43.

³ Tait, *Properties of Matter*, 4th ed., London, 1899, p. 264.

⁴ If a capillary tube is used, a side tube, provided with a good stop-cock, sealed into the wider part of the vertical tube is required in order to enable one to fill the apparatus with water. This form possesses the advantage that under favorable circumstances the rise may amount to several centimeters in the course of a few minutes.

at one end and at the other end made fast¹ to a disk, ball, or other fragment of porous material; the tube is filled with water and inverted in a vessel of mercury (Fig. 2). The capillary effects in

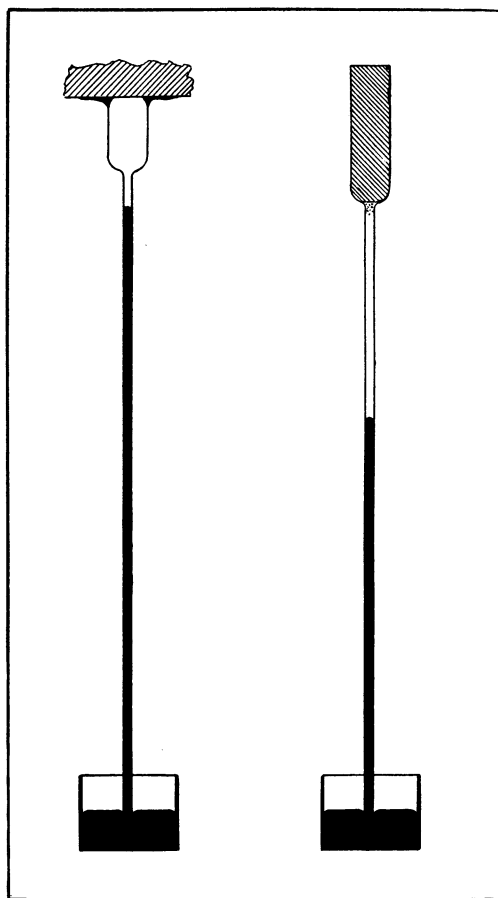


FIG. 2.—Forms of atmometer

the fine pores of the material are such that not only is the water in the tube kept supported but, as evaporation from the surface proceeds, mercury rises to take the place of the water to a height

¹ By means of sealing-wax, beeswax-rosin, or in any other appropriate way. The joint must of course be absolutely gas-tight.

which may equal, or even exceed, the barometric height.¹ The mercury rises gradually—provided that the pores are not too fine—maintains the equilibrium position for some time, and then drops back rapidly; the rate of rise, which depends upon a number of factors, does not concern us here. The position of equilibrium is the important thing; it depends only upon the size of the widest pores at the free surface and the surface tension between water and the porous material; results for samples of various materials, as observed by us, are brought together in Table I. But before considering these results we shall give a brief outline of the theory of capillarity in so far as it concerns the question at issue; for the pores are in effect merely fine capillary tubes.

OUTLINE OF THE THEORY OF CAPILLARITY²

The general principle to be borne in mind is that the rise of liquid in any capillary tube is primarily a measure of the pressure discontinuity at the curved free surface of the liquid within the tube.

It can easily be shown that the pressure difference (Δp) between the two sides of a curved surface separating two fluids is expressed by the formula:

$$\Delta p = \sigma \left(\frac{1}{\rho} + \frac{1}{\rho'} \right) \quad (1)$$

where σ is the surface tension and ρ and ρ' the radii of curvature in two planes at right angles to one another. If the surface is spherical, $\rho = \rho'$ and the expression takes the simple form

$$\Delta p = \frac{2\sigma}{\rho} \quad (2)$$

¹ Thus G. A. Hulett (*Zeitschr. d. physik. Chem.*, XLII (1903), 359, who made experiments of this type using a porous porcelain plate in which copper ferrocyanide had been deposited, observed in one instance a height of 110 cm. of mercury; in this case therefore there was a negative pressure, amounting to about half an atmosphere, acting upon the water close to the under side of the porcelain disk. Similar experiments had previously been made by E. Askenasy, *Verhand. naturh. med. Verein Heidelberg*, March, 1895. This process, it may be remarked, is the commonly accepted mode of accounting for the rise of sap in trees.

² Capillarity is treated in any textbook of physics, though not always well. The discussion of it by Tait in his *Properties of Matter* is exceptionally clear.

A slight modification of this formula is directly applicable to the capillary rise of liquids in fine tubes. Consider a tube, open at both ends, partly immersed in a vessel of liquid, which will rise in the tube to a certain height h (Fig. 3). When the rise is several

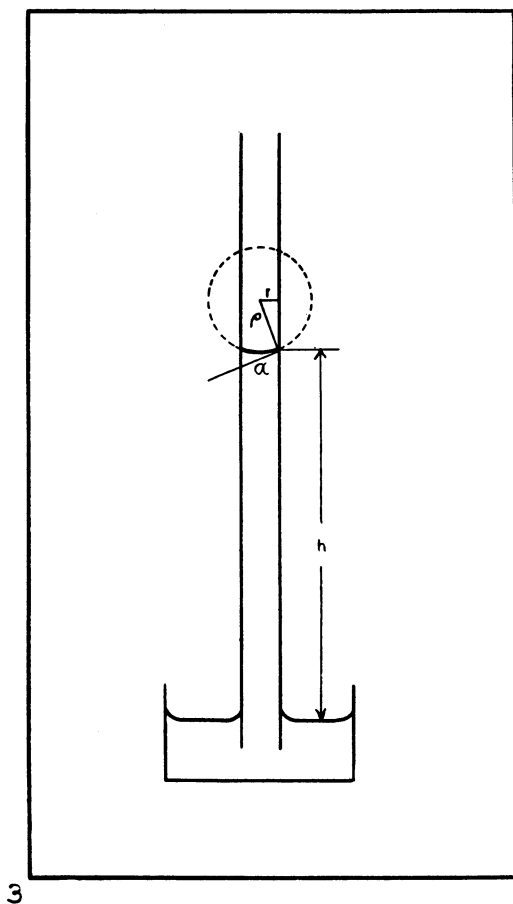


FIG. 3.—Diagram

times the diameter of the tube, the curvature of the free surface in the tube is sensibly uniform; in other words, the surface is a segment of a sphere whose radius is ρ . Now, according to equation 2, the pressure on the under side of the curved surface

is less than that on the upper side by an amount equal to $\frac{2\sigma}{\rho}$; at the same time, however, this pressure difference is equal to the hydrostatic head of a column of the liquid of height h . That is,

$$\frac{2\sigma}{\rho} = h g d$$

where g is the intensity of gravitation and d the density of the liquid. Moreover, if α is the angle of contact between liquid and tube, $\rho = r \cos \alpha$, where r is the radius of the tube; hence,

$$h = \frac{2\sigma \cos \alpha}{r g d} \quad (3)$$

which is the familiar formula for the rise of liquids in capillary tubes.

In the case of water in contact with many substances, $\alpha = 0^\circ$ and the equation reduces to the form

$$h = \frac{k\sigma}{r}. \quad (4)$$

For water at a temperature of 18° , provided that h and r are expressed in centimeters,¹ k has the value 0.00204 and σ , the surface tension in dynes per cm., is 74. The development of this formula directly from the basis that there is a definite pressure discontinuity at a surface of separation seems worthy of emphasis since it affords us a clearer insight into the more complicated problems of capillarity.² Starting from this basis, a number of conclusions are immediately obvious; we state them here because they have not been

¹ If h and r are expressed in millimeters, the constant k must be increased, not tenfold, but one hundred fold.

² Incidentally it may be remarked that by the same reasoning the pressure within a small drop of water is greater than the external pressure; the water is thus under greater pressure than the vapor derived from it. Now this type of pressure—"unequal" pressure—raises the vapor pressure of the liquid; consequently the vapor pressure of a drop is greater the smaller the radius of curvature of its surface—a well-known conclusion which is exceedingly important in regard to a large number of phenomena. In a perfectly analogous way the vapor pressure in equilibrium with the curved surface of a liquid in a capillary surface is smaller than its vapor pressure as ordinarily given; and this lowering of vapor pressure is greater the smaller the diameter of the tube. Similarly (if it be permissible to speak of the surface tension of solids) one may deduce the fact that the solubility of a substance increases as the size of grain decreases.

apparent to all who have adduced capillary effects as a means of accounting for geological phenomena.

(A) Since the pressure discontinuity occurs only at the *surface of separation*, a column of liquid (as in Fig. 2, for example) can be supported *only when there is a free liquid surface within the capillary*; in the case of porous materials, therefore, only when there are surfaces of separation within the pores.¹

(B) When equilibrium has been established, the height attained by the liquid in a tube depends only upon the bore of the tube at the surface of separation (since it is this which determines the curvature) and not in any way whatever on the size or shape of the rest of the tube. This statement however by no means implies that liquid will rise in material containing pores of irregular diameter to the height corresponding to the width of pore observed at the surface of a fragment of the material.

(C) Consider an open tube, shorter than the height of column of water which it would support, which is filled with water and placed so that its lower end dips below a mercury surface. The free water surface assumes a curvature sufficient only to support the existing column of water; but if water be removed from the top (by evaporation, or otherwise) the curvature becomes greater, and consequently mercury is pulled up into the tube. This process continues until the surface is hemispherical, when it supports a column of mercury and water equivalent in weight to the (much longer) column of water alone which it would support. This is virtually the atmometer, the only difference being that in the latter there are a very large number of pores; we see moreover that the height at equilibrium is determined by the width of the largest pores in the material at the surface of separation.

(D) The pressure discontinuity at the surface of separation—which we may look upon as a pressure exerted by the surface film of water in an endeavor to contract itself—is precisely the same in amount whether it make itself manifest (a) by supporting a column of liquid; (b) by compressing the air in a tube closed at one end and wholly immersed in water; (c) in the form of the pressure

¹ This of course includes the case where the liquid in the pores extends practically to the surface of the material as a whole.

required to cause air to begin to flow through a capillary tube (or pore) which originally contained water.¹

(E) The capillary rise is affected by variation of those factors which influence the angle of contact and the density and surface tension of the liquid. The changes induced in the angle of contact and in density may for present purposes be neglected entirely. As regards the influence of temperature on the surface tension of water, all the investigations unite in showing that its surface tension decreases regularly with rise of temperature, becoming zero of course at the critical temperature, where there is no surface of separation. The relation is practically linear when the whole range is considered; it may be represented with sufficient accuracy by the formula

$$\sigma_t = 78 - 0.21 \, t \text{ or } 0.21 (370 - t)$$

where σ_t is the surface tension at t (temp. in Centigrade) expressed in dynes per centimeter.

The effect of pressure on surface tension is unknown, but is presumably small. For the changes in the properties of water induced by a pressure of, say, 1,000 atmospheres are usually similar in magnitude and direction to those observed when a relatively small quantity of a salt is dissolved in it; and the surface tension of such dilute (0.5 *N* or less) solutions differs by only a few per cent from that of pure water.

Experimental.—Before proceeding to the discussion of the geologic implications of the above principles, we shall mention the results of a few experiments on the atmometer principle, carried out with cylinders or fragments of various materials. It may be mentioned that the cylinders of cement and the plaster of paris were cast in glass tubes of appropriate length, which then served

¹ Experiments of this kind have been made by Barus (*Am. Jour. Sci.*, XLVIII [1894], 452), by Bechhold (*Zeitschr. d. physik. Chem.*, LXIV [1908], 328) and by Bigelow and Bartell (*Jour. Am. Chem. Soc.*, XXXI [1909], 1194). The formula connecting pressure required (P , in atm.) with pore diameter (D , in millimeters) is $P = 0.00304/D$ (for room temperature); it is easily derived from formula 3. Bechhold's calculated pore diameters are tenfold too small, a fact which was noted by Bigelow and Bartell. The pressure P is of course not the same as that required to force water to flow through a capillary tube; for in the latter case we do not necessarily have a free surface within the tube.

directly for the experiment; this insured that evaporation occurred, not at the sides, but at the upper surface only. Likewise, evaporation of water at the lateral surface of the sandstones was prevented by coating them with wax. The observations are brought together in Table I, to which we append a few results obtained by Bigelow and Bartell,¹ who determined the air pressure required to just force water out of the pores of the material.

TABLE I
RESULTS OF ATMOMETER EXPERIMENTS WITH VARIOUS MATERIALS

MATERIAL		RELATIVE RATE OF RISE	EQUIVALENT HEIGHT OF MERCURY COLUMN CM.	VIRTUAL HEIGHT OF WATER COLUMN SUPPORTED CM.	EQUIVALENT PRESSURE DIFFERENCE ATM.	CALCULATED DIAMETER OF PORES μ *
Kind	Thickness of Layer Cm.					
"Alundum"	0.5	50	10.5	143	0.14	21
Refractory clay	0.5	75	16.3	222	0.21	14
Pressed magnesia	0.6	35	18.5	250	0.24	12
Porcelain	0.2	100	59.6	810	0.79	3.8
Portland cement	5	20	Did not come to equilibrium; pressure difference at equilibrium presumably greater than 1 atm.			<3
Plaster of Paris	5	20				
Marble	3	5				
Diorite	3	0.1				
Sandstone (Daubrée)	2	.....	.....	.....	0.8	2.7†
Porcelain . . . . .	—	.....	.....	.....	2.5‡	1.2
Porcelain . . . . .	—	.....	.....	.....	15.0‡	0.19

* $1 \mu = 0.001$ mm. The wave-length of the D line is 0.5μ .

† Direct observations of Bigelow and Bartell.

‡ This result is calculated from Daubrée's data as follows: The pressure of 1.8 atm. recorded by him corresponds, as he himself points out, to a temperature of 113° at the lower surface of the sandstone. At this temperature the surface tension of water is 54.3; the pressure exerted by the capillary curved surface is 0.8 atm., corresponding to a column of water 830 cm. in height. Consequently from equation (4), $r = 0.00134$ cm. or $D = 2.7 \mu$.

These results are not especially characteristic of the material; they pertain merely to the particular samples which we happened to use, and correspond to the widest pores in those samples. Moreover we have observed that the differences for layers of the same material of different thickness are no greater than one would expect from the probable variation in size of the widest pores.

From what has gone before, it is obvious that the Daubrée experiment is in principle identical with the experiments just

¹ Bigelow and Bartell, *Jour. Am. Chem. Soc.*, XXXI (1909), 1194. Analogous experiments have also been made by others.

described; that his temperature and temperature difference played no part further than the subsidiary one of decreasing the surface tension of the water and hence the observed pressure difference. Thus it was possible to include in Table I the calculated pore diameter of Daubrée's sandstone as deduced from his values of temperature and pressure difference.

GEOLOGICAL BEARINGS

As long ago as 1881, Osmond Fisher pointed out¹ that the Daubrée experiment was effective merely because there was a surface of separation; and as Kemp,² in citing his opinion, writes:

The experiment gives no ground for thinking that water would move through the heated walls confining a reservoir of molten rock and become involved in the latter.

To quote from Osmond Fisher:

Capillary action can be made to do great things. . . . But it cannot cause a liquid to flow continuously through a tube, however short; for, if it could, it would give us perpetual motion. . . . If there were a cavity filled with vapor, it is possible that the density of the vapor, and therefore its pressure, might be increased to a certain extent, by the evaporation of the water from the extremity of the capillary tubes, and that was what occurred in the experiment of M. Daubrée. . . . Still further, the existence of capillary communication of water from the surface may be doubted. For if there were supposed a capillary tube extending from the bottom of the ocean, the pressure at the lower end of this tube would be that of the water contained in it *plus* that, if any, arising from capillarity, while the pressure of the crust around its mouth would be that due to the weight of the crust. This latter would be the greater of the two: consequently the liquid upon which the crust rested, having a tension [being subject to a pressure] equal to the weight of the crust, would force back the water in the tube, and if it were not too viscous would itself occupy the tube.³

Now it is hard to imagine a permanent configuration, except for comparatively small depths, such that this closing-up of the

¹ Osmond Fisher, *Physics of the Earth's Crust*, London, 1889, 2d ed., p. 143.

² J. F. Kemp, "Rôle of Igneous Rocks in the Formation of Veins," *Trans. Am. Min. Eng.*, XXXI (1901), 177.

³ *Op. cit.*, pp. 144-45. We may note that the argument does not postulate that the material under the "crust" be liquid in the restricted sense of the word; it is valid if the rocks at that depth can flow, a condition which surely obtains except at comparatively shallow depths.

pores by the plastic rock should not occur. Indeed it is hard to conceive of the existence, at any considerable depth, of continuous spaces, unless they be very small;¹ and if they be small and traversed by water, it would appear that they must in a very short time become choked up with material deposited by the water when it evaporates. This point has already been discussed by R. T. Chamberlin,² who agrees in thinking that capillary force is quantitatively inadequate; and after adducing various lines of evidence writes: "All of these facts and deductions lead to the general conclusion that our surface-waters have been derived from the interior of the earth, and oppose the idea that to explain the presence of hydrogen, or water, in magmas and rocks, we have merely to appeal to the penetration of surface-waters."

In order to show the quantitative significance of capillarity we present in Table II calculated values of the pressure producible by capillarity at various depths, assuming a temperature gradient of (1) 1° C. per 30 meters, which is about the normal (so far as one can judge from the present very faulty data) (2) 1° C. per meter, which must be nearly the maximum gradient possible, even in the vicinity of volcanoes. In making these computations we have taken into account the variation of surface tension (σ) with temperature, but have neglected the (unknown) effect of pressure; we have also neglected the influence of temperature and pressure (a) on the angle of contact a (b) on the density of water, which enters as a factor (1) in the value of k proper to each temperature and (2) in the calculation of the hydrostatic pressure. In calculating the pressure due to the overlying rock, a mean rock density of 2.7 was assumed. The values given in Table II are therefore approximate only, but nevertheless are amply accurate for the present purpose. Such figures can be used to support geological speculations with regard to the penetration of water into deep-seated rocks only if both of the following restrictive conditions can be considered to be fulfilled: (1) that pores persist to the depth in question; (2) that the rock mass adjoining the mouth of the pore shall be

¹ As to the depth to which spaces may persist, see F. D. Adams, *Jour. Geology*, XX (1912), 97-118, and L. V. King, *ibid.*, 119-38.

² "The Gases in Rocks" (*Carnegie Inst. Publication No. 106*, 1908), 70-75.

exposed to a pressure lower than the total pressure to which the water just within the pore is subject. The latter condition would appear to be equivalent to the assumption that, excepting the cases where the capillary pressures are relatively large (i.e., at small depths with very fine pores), the rock mass or magma in question is situated in some sort of cavity, the walls of which protect it from the full load due to the weight of the overlying strata.

TABLE II

TO INDICATE THE MAGNITUDE OF THE PRESSURES (IN KG. PER SQ. CM.*) PRODUCIBLE BY CAPILLARITY UNDER VARIOUS CONDITIONS; THE VALUES GIVEN ARE APPROXIMATE AND SUBJECT TO THE ASSUMPTIONS STATED ABOVE

DEPTH METERS	PRESSURE DUE TO HYDRO- STATIC COLUMN	CAPILLARY PRESSURES FOR PORE DIAMETERS OF			TOTAL PRES- SURE INSIDE PORES OF DIAM. 0.01 μ	PRESSURE OUTSIDE PORES DUE TO OVER- LYING ROCK
		100 μ	1 μ	0.01 μ		
Temperature Gradient, 1° C. per 30 Meters						
100.....	10	0.03	3.1	306	316	27
200.....	20	.03	3.0	302	322	54
500.....	50	.03	2.9	294	344	135
1,000.....	100	.03	2.8	278	378	270
2,000.....	200	.03	2.5	250	450	540
5,000.....	500	.02	1.6	160	660	1350
10,000.....	1000	.002	0.2	20	1020	2700
20,000.....	2000	.000	0.0	0	2000	5400
Temperature Gradient, 1° C. per Meter						
50.....	5	0.03	2.6	264	269	14
100.....	10	.02	2.2	220	230	27
200.....	20	.01	1.3	131	151	54
300.....	30	.005	0.5	50	80	81
400.....	40	.000	0.0	0	40	108

* 1 kg. per sq. cm. = 0.97 atm.

From this table it is evident that the pressure producible by capillarity is insignificant in comparison with the hydrostatic pressure, except for very fine pores. For each size of pore there is a definite depth above which the combined hydrostatic and capillary pressure exceeds the rock pressure, and below which the rock pressure (presuming that it is fully effective) predominates. For instance, in pores of 0.01 μ diameter and with the normal temperature gradient, the depth at which the opposing pressures just

balance is about 1600 meters; and this depth varies inversely as the pore diameter.¹

It is evident therefore that capillarity plays a minor rôle unless the pores are very small; and this minuteness of the pores leads us to inquire what amount of water could actually flow through them. This quantity can be calculated by application of the well-known Poiseuille formula, by means of which the rate of flow can be calculated if the radius of the tube, the pressure gradient, and the viscosity of the liquid are known. Hence, assuming the mean viscosity of the water to be 0.005 (its value at a temperature of 30°), the amount of water flowing through a pore of diameter $1\ \mu$ (i.e., $\frac{1}{25000}$ inch) would be about 15×10^{-6} c.c. per year; a value which will tend to be too high, since the Poiseuille formula applies to straight pores of uniform circular cross-section, whereas those in the rocks are zig-zag and altogether irregular in shape.

Now if we make the very generous estimate that 10 per cent of the volume occupied by the rock consists of pore-spaces, there will be one million (10^6) pores of $1\ \mu$ diameter in each square centimeter. On these assumptions, therefore, the quantity of water flowing would be only 15 c.c. per sq. cm. of surface per year; and the assumptions are such as to tend apparently to make this result too large, rather than too small. But from Table II it is evident that capillarity is quantitatively negligible at any considerable depth in pores of $1\ \mu$ diameter; in finer pores, on the other hand, where the pressure producible by capillarity is relatively important, the quantity of water in flow is absolutely insignificant. Thus, if the diameter of the pores is (a) $0.1\ \mu$ (b) $0.01\ \mu$, and on the assumption again that the proportion of total pore space is 10 per cent,² the amount of water flowing would be (a) 0.15 (b) 0.0015 c.c. per sq. cm. of surface per year. In the latter case, in other words, a period of 1,000 years would be required for a quantity of water equivalent to 1.5 cm. (about one-half inch) of rain to flow past a given horizontal plane; moreover, the adoption of any reasonable assumptions other than those used above would not, we feel sure, increase these calculated values more than tenfold. In connection with this, we would remark only that water percolating

¹ At least, this is true with sufficient approximation for the present purposes.

² This corresponds to (a) 10^8 (b) 10^{10} pores per sq. cm. of surface.

into a magma (presuming for the moment that it is possible) at this rate would be very little likely to produce any very violent effects.

The foregoing statements, of course, by no means imply that water cannot, and does not, penetrate, by capillary action or otherwise, to a considerable depth into the upper and cooler layers of the crust of the earth. Indeed the preceding figures and arguments tend to show that water would be likely to occur in appreciable quantities down to depths of about 500 meters (1,500 feet) and in minute quantities down to perhaps 1,500 meters (5,000 feet)—a conclusion which is, we believe, entirely borne out by experience.

CONCLUSION

The Daubrée experiment on the passage of water through a disk of sandstone against a certain counter pressure of steam is, as has indeed been pointed out by others, an example of the effects producible by capillarity. The same effect may be obtained, and much more simply, by atmometer experiments such as we describe. The magnitude of the possible effect under various conditions may therefore be deduced from the laws of capillarity. Capillary forces are effective only when there is a surface of separation within the pores; moreover they diminish steadily with rise of temperature, and vanish at the critical point of the liquid. Calculation shows that the effects producible at any considerable depth are, in comparison with the pressure due to the hydrostatic column, insignificant except in pores of such fineness that the amount of water which could flow through them is infinitesimal.

It appears therefore as if the probabilities were all against the notion that appreciable amounts of meteoric water can ever penetrate into deep-seated and highly heated rock masses. We feel therefore that the burden of proof should now be imposed on anyone who asserts the contrary, for, even if some unconsidered factors intervene to upset the calculations of the foregoing pages, he would still be confronted with the difficulty of imagining a reasonable configuration of the rock in depth, such as would insure that the total pressure within the pore is not overbalanced by the pressure to which the plastic rock surrounding it exerts.